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Growth of Holstein calves from birth to 90 days:
The influence of dietary zinc and BLAD status[1]

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ABSTRACT: The main objective of this study was to describe Holstein neonatal growth and development as influenced by dietary zinc supplementation and the *CD18* genotype, both of which may affect immune competence. Holstein calves (n = 421), after being fed colostrum, were brought to a calf facility, randomly assigned to one of four zinc supplementation groups (control at 40 mg Zn/kg DM or the control diet supplemented with an additional 60 mg Zn/kg DM provided as either zinc sulfate, zinc lysine, or zinc methionine), weighed, and measured for morphometric growth parameters. Measurements were repeated at 30, 60, and 90 d. Calves were also genotyped for the presence of the mutant D128G *CD18* allele, which, if present in two copies, causes bovine leukocyte adhesion deficiency. Zinc supplementation above 40 mg Zn/kg DM, regardless of the chemical form, did not accelerate growth ($P > 0.25$). Further, overall calf growth performance was not suppressed or improved ($P > 0.4$) in calves heterozygous at the *CD18* locus relative to calves homozygous for the normal *CD18* allele, although genotype negatively affected some morphometric measurements ($P < 0.05$). Using these data, quadratic models of early growth were generated as a preliminary step to develop growth criteria that will allow producers, veterinarians, and animal scientists to identify poor growth performance early in neonatal life. Such criteria provide the basis for tools to improve economic performance.

Key Words: Calves, Cattle Diseases, Growth, Zinc

Introduction

Optimal growth for replacement dairy heifers has been described as reaching lactation potential at the desired age with minimal expense (Swanson, 1960). Controversy surrounds dairy replacement heifer growth rate and the optimum age at first calving (Sejrsen and Purup, 1997; Heinrichs, 1998). The large capital investment required to raise dairy heifers (Goodger et al., 1989) argues to calve heifers at less than 24 mo of age (Hoffman, 1997; Van Amburgh et al., 1998). Early calving demands accelerated prepubertal growth (Stelwagen and Grieve, 1992; Heinrichs, 1998). Holstein growth beyond 90 d has been described (Heinrichs and Hargrove, 1987; Koenen and Groen, 1996), but few reports characterize growth from birth to 3 mo for contemporary Holsteins. Developing regression equations describing early calf growth that include factors related to immune function will better define the relationships between early growth and subsequent performance.

Immunosuppression, poor growth, and death in Holstein calves have been attributed to zinc deficiency (Graham et al., 1987; Mourits et al., 1997). The NRC (1989) recommended zinc to be fed at 40 mg/kg; rations typically exceed that level of zinc supplementation with little data to support or dispute such a need. Also influencing immune function and growth is a genetic mutation in *CD18* (Shuster et al., 1992). Calves homozygous for the bovine leukocyte adhesion deficiency (**BLAD**) mutation have recurrent bacterial infections, grow poorly, and rarely survive their 1st yr (Kehrli et

al., 1992). Although the frequency of BLAD carriers in the Holstein population is declining (Powell et al., 1996), the presence of a single mutant BLAD allele may affect early calf growth. This study was designed to describe growth parameters from birth to 90 d of age in Holstein calves, to determine whether calves fed zinc in excess of the NRC (1989) recommended amount had a growth advantage, and to test whether BLAD heterozygosity adversely affected growth.

Materials and Methods

Animals

Holstein calves (n = 421) were brought into the calf facility after being fed 3.8 L of colostrum at the dairy of origin. Calves were sequentially allocated into a treatment group (n = 105/group) and a color-coded identification tag was placed in the left ear of each calf. Each calf was injected with 500,000 IU vitamin A and 75,000 IU vitamin D (Boehringer Ingelheim Animal Health, St. Joseph, MO and Butler Co., Dublin, OH). Calves were maintained in individual hutches throughout the trial and fed milk twice daily until weaned. Calves were vaccinated for infectious bovine rhinotracheitis (**IBR**) and parainfluenza type 3 (**PI3**) with an intranasal vaccine (Nasalgen, Schering-Plough, Omaha, NE) in the 1st wk of life. This was repeated at 4 wk of age. Male calves were implanted at 30 d of age with 36 mg zeranol (Ralgro, Schering-Plough, Union City, NJ) and surgically castrated at 60 d of age. Calves were dehorned and females had permanent identification tags placed in both ears at 4 wk of age. Calves were revaccinated for IBR and PI3 and vaccinated for bovine virus diarrhea, bovine respiratory syncitial virus, leptospirosis, and clostridia and given vitamins A and D (dosages above) at 10 wk of age. All calves were weaned at 90 d of age.

Diets

Calves were fed 3.8 L/d whole pasteurized waste milk containing one of four zinc supplement levels: 40 mg Zn/kg DM (no additional zinc; Control) or 100 mg Zn/kg DM milk (60 mg Zn as zinc sulfate, zinc methionine or, zinc lysine added to the control milk). This was based on the assumption that milk was 87% water and contained an average of 3 to 5 mg Zn/L (Lin et al., 1986). Thus, 1 L of whole milk was supplemented with 60 mg Zn (based on the assumption that the milk contained 5 mg Zn/L and was 13% DM, corresponding to approximately 40 mg Zn/kg DM). Although the zinc content of all waste milk used was not evaluated, zinc content was determined by a wet-ashing technique (Graham et al., 1987) on 12 random samples, yielding results similar to published zinc values (Hurley, 1980). The zinc supplements were solubilized in warm milk for 30 min prior and were then thoroughly mixed into the bulk milk fed to the calves. Calves were fed concen-

Table 1. Ingredient composition of concentrate fed to calves from birth to 90 d

Ingredient	g/kg, as-fed basis
Steam-rolled barley	248.1
Steam-rolled corn	97.7
Steam-rolled oats	82.7
Cottonseed hulls	120
Decoquinate pellet 0.125%	15
Propionic acid	2
Blended feeding fat	20
Cane molasses	86.6
Ground corn	22.5
Ground barley	30
Beet pulp	10
Wheat millrun	62.5
Soybean meal	164.9
Vitamin and mineral pellet[a]	37.5

[a]Supplemental vitamin and mineral pellet composition (g/kg DM basis): ground corn (250), rice bran (280), cobalt sulfate (0.075), copper sulfate (2.5), calcium iodate (0.075), iron sulfate (4.0), ground limestone (295), magnesium oxide (38.75), manganous sulfate (8.75), dicalcium phosphate (45), potassium/magnesium sulfate (5.0), potassium chloride (12.5), sodium chloride (45), sodium selenite (0.725), vitamins A (0.763), D (0.2) and E (1.975), and mineral oil (5.0).

trate diet free choice from birth. Concentrate diets for the four calf groups were either basal diet containing 40 mg Zn/kg DM in accordance with the NRC recommendation (NRC, 1989) for the control group or the basal diet further supplemented with an additional 60 mg zinc in the form of zinc sulfate, zinc lysine, or zinc methionine. Thus, the final zinc concentration was 100 mg Zn/kg for the three zinc-supplemented treatment groups. The concentrate diets were formulated using the proportions and ingredients listed in Table 1. The chemical composition of the concentrate diet, listed in Table 2, was analyzed by A and L Western Agricultural Laboratories (Modesto, CA). The zinc concentration of the concentrate diet was determined as previously described (Clegg et al., 1981; Graham et al., 1987).

Data Collection

Calves were weighed and morphometric measures determined after colostrum ingestion and upon arrival at the calf ranch (approximately 12 to 36 h after birth). Morphometric measures and BW determination were repeated at 30-d intervals until weaning (i.e., birth, 30, 60, and 90 d of age).

Length of the antebrachium, tibia, metatarsus and metacarpus, metatarsal and metacarpal circumference, head length and width, and height at the withers were used to determine growth velocity during each interval. All measurements were taken on the left side, with limbs in a flexed position. Calf height and BW were determined while calves stood. Metacarpal and metatarsal circumferences were measured at the narrowest point of the diaphysis using a flexible tape measure. Tibial length was measured with a caliper from the tibial crest to the flexor surface of the hock. Ante-

Table 2. Chemical composition of concentrate diet fed to calves from birth to 90 d

Item	Composition[a]
Crude protein, g/kg	174
Crude fat, g/kg	53.2
Crude fiber, g/kg	101.3
ADF, g/kg	154
NDF, g/kg	268
Ash, g/kg	63
Calcium, g/kg	7.1
Phosphorous, g/kg	5.6
Sodium, g/kg	1.3
Chloride, g/kg	2.4
Magnesium, g/kg	3.2
Potassium, g/kg	11.4
Sulfur, g/kg	3
Vitamin E, IU/kg	43
Vitamin A, KIU/kg	21.5
Vitamin D, KIU/kg	4.4
Iodine, mg/kg	2.06
Selenium, mg/kg	0.63
Iron, mg/kg	155
Copper, mg/kg	43.3
Cobalt, mg/kg	1.35
Zinc, mg/kg	34.86
Manganese, mg/kg	129.5

[a]The basal diet contained 40 mg/kg Zn, which was supplemented with an additional 60 mg/kg Zn provided in the sulfate, methionine, or lysine form for the three treatment groups.

Table 3. Descriptions and numbers of experimental calves by sex, zinc group, twin status, and *CD18* genotype

Item	Females, no.	Males, no.
Total	204	203
Zinc group		
Control	52	51
Zn Sulfate	51	51
Zn Methionine	51	50
Zn Lysine	50	51
Twin status		
Single	187	169
Twin	17	34
CD18 genotype		
Normal	171	183
Heterozygous BLAD	33	20

brachium length was measured from the olecranon process to the intercarpal joint (articulatio mediocarpea). Metacarpal length was measured on the cranial surface from the proximal surface of the metacarpus (carpal to metacarpal joint; articulatio carpometacarpea) to the distal surface of the metacarpus at the metacarpalphalangeal joint. Metatarsal length was measured on the cranial surface from the point of the hock (external surface of the calcaneum) to the distal surface of the metatarsus at the metatarsalphalangeal joint. Body length was measured from the point of the shoulder (acromion process of the scapula) to the tuber ischii. Head length (nose to crown) was measured over the dorsal surface of the cranium from the occipital crest to the nasal planum. Head width was measured behind the caudal border of the mandibular ramus and in front of the ears (external pinnae). Height at withers was measured from the base of the hoof to the highest point at the level of the scapula. Body condition score was determined when each calf was weighed using a scale of 1 (thin) to 5 (fat) as described by Ferguson (Ferguson et al., 1994).

CD18 **Genotype**

CD18 genotype (homozygous normal or heterozygous for the BLAD mutant allele) was determined by isolating DNA from blood collected at birth in EDTA tubes, subjecting it to PCR, and screening for the presence of characteristic RFLP patterns (Shuster et al., 1992).

Statistical Analyses

Only individuals with BW and bone measurements recorded for all ages were included in the analyses (n = 407). Basic descriptive data on female and male calves can be found in Table 3. Several complementary analyses for BW, length, height, and condition, length of head, radius, metacarpal, metatarsal, and tibia, head width, and metacarpal and metatarsal circumference were undertaken. To facilitate future predictive use of these data and evaluate the effect of zinc supplementation (four diets), BLAD status (heterozygous or homozygous normal at *CD18*), and twin status on growth, a polynomial regression was fit separately for each sex. This model included linear, quadratic, and cubic terms for BW, as well as categorical classification for zinc supplementation group, BLAD status, and twin status. Being repeated measurements on the same calf, a term for a random animal effect (nested within the twin by zinc group by BLAD status interaction) was included as well, along with all two-way interactions among fixed classifications. A term for sex is not included in this model because analyses were conducted separately for each sex. Additional analyses were performed with day of age as the continuous variate for the polynomial regression, in place of BW. Models for which the two-way interactions were not a significant explanatory variable were reevaluated with these interaction terms removed from the model.

A second analysis was the regression of BW on each of the various bone measurements through the allometric power function. The intent here was to better understand the rate of bone growth during this early phase of life. To fit the allometric power function requires only a regression of the natural log of the bone measures on BW. A term for animal was also included to accommodate the repeated nature of the observations on each animal over the course of the trial, as well as terms for treatment group, BLAD status, and twin status. All computations were performed with the GLM procedure of SAS (SAS Inst. Inc., Cary, NC).

Table 4. Growth measures at birth and 30, 60, and 90 d of age in Holstein female[a] (F, n = 204), and male (M; n = 203), calves[b]

	Age											
	Birth			30 d			60 d			90 d		
Item	F	M	SE	F	M	SE	F	M	SE	F	M	SE
BW, kg	41.1	44.2	0.2	50.5	55.6	0.2	75.3	83.6	0.2	104.2	114.0	0.3
Body length, cm	70.0	71.6	0.2	75.3	77.2	0.2	83.0	85.4	0.2	93.7	95.6	0.2
Height, cm	75.4	77.6	0.2	79.5	81.2	0.2	84.6	86.2	0.1	90.6	92.2	0.1
Body condition	3.0	3.0	0.03	3.0	3.0	0.04	3.1	3.2	0.04	3.0	3.1	0.04
Head length, cm	25.4	25.9	0.1	27.0	27.4	0.1	29.3	29.9	0.1	31.8	32.4	0.1
Radial length, cm	25.2	25.7	0.1	26.0	26.6	0.1	27.4	28.3	0.1	29.2	29.8	0.1
MC length, cm[c]	19.6	20.0	0.1	20.1	20.4	0.1	21.1	21.4	0.1	22.0	22.5	0.1
MT length, cm[c]	32.1	32.9	0.1	33.3	33.9	0.1	34.90	35.8	0.1	36.4	37.2	0.1
Tibial length, cm	27.5	28.0	0.1	28.7	29.1	0.1	30.8	31.7	0.1	32.4	33.2	0.1
Head width, cm	12.4	12.9	0.1	12.9	13.2	0.1	13.7	14.1	0.1	14.7	15.0	0.1
MC circ., cm[c]	11.1	11.9	0.1	10.7	11.5	0.1	11.4	12.1	0.1	12.3	13.0	0.1
MT circ., cm	11.7	12.4	0.1	11.4	12.1	0.1	12.4	13.0	0.1	13.6	14.2	0.1

[a]Sexes were analyzed separately.
[b]Zinc treatment had no effect on any parameter measured, nor were there zinc × sex or zinc × twin interactions ($P > 0.2$).
[c]MC stands for metacarpal, MT stands for metatarsal, and circ. stands for circumference.

Results

Male calves were heavier and had larger skeletal dimensions ($P < 0.003$) than female calves (Table 4). Average daily gains of male calves from birth to 30 d, 30 to 60 d, and 60 to 90 d were 0.38 ± 0.03, 0.93 ± 0.03 and 1.01 ± 0.04, respectively. Average daily gains of female calves for the same time periods were 0.31 ± 0.03, 0.83 ± 0.03, and 0.97 ± 0.03, respectively. Twin calves were smaller than single calves at birth and remained smaller throughout the trial (Table 5, $P < 0.05$).

Zinc concentration in the four diets was as follows: 39.39 ± 1.14 mg Zn/kg DM (control), 95.36 ± 3.08 mg Zn/kg DM (zinc sulfate), 101.66 ± 3.19 mg Zn/kg DM (zinc methionine), and 97.45 ± 1.46 mg Zn/kg DM (zinc lysine). There were no differences ($P > 0.25$) among zinc groups for any of the measured variables; therefore, calf data for all diets were pooled for further analysis. The average mean BW and growth parameters of calves across all four zinc supplementation groups are presented in Table 4.

Table 5. Mean body weights ± standard errors (kg) of female and male single and twin calves over time[a]

	Age			
Item	Birth	30 d	60 d	90 d
Female				
Single	41.2 ± 0.2	51.0 ± 0.2	76.1 ± 0.2	105.1 ± 0.3
Twin	35.8 ± 0.8	44.9 ± 0.7	67.0 ± 1.1	95.1 ± 1.3
Male				
Single	45.9 ± 0.2	57.2 ± 0.2	85.7 ± 0.3	116.1 ± 0.3
Twin	36.3 ± 0.5	47.7 ± 0.5	73.6 ± 0.6	103.3 ± 0.8

[a]At any given age, within a sex, the twin calves weighed less than their single counterpart ($P < 0.05$).

To generate a predictive model of normal calf growth during the early neonatal growth phase, data were fit to various regression models, allometric, linear, and cubic, with no improvement in fit over the quadratic model. Results of the quadratic model are in Table 6 for female and male calves. The R^2 values from the regressions show that BW, body length, head length, and height ($P < 0.001$) were most highly correlated to age in females ($R^2 = 0.96$, 0.93, 0.93, and 0.91); BW, body length, and head length were most highly correlated to age in males ($R^2 = 0.96$, 0.91, and 0.94).

The final model developed examined the relationship between age, twin status, and BLAD status in males and females (Table 7). Twin status was statistically important ($P < 0.001$) for nearly all growth measurements. The model indicated that twin calves at birth were smaller than singles and remained smaller throughout the entire trial. The prevalence of animals heterozygous for the mutant BLAD allele was 13% for all calves; 16.2% of females and 9.9% of males were heterozygous at the *CD18* locus. When the effect of the *CD18* genotype was evaluated, mean BW of calves heterozygous for the BLAD mutant allele were not different from the mean BW of calves homozygous normal at any age ($P > 0.05$). The BLAD genotypic status was statistically different only for head width in females ($P < 0.001$). Female calves heterozygous for BLAD had smaller head widths than homozygous normal females. In this complete model, female calf BW, body length, head length, and height were most closely correlated with age ($R^2 = 0.96$, 0.93, 0.93, and 0.91, respectively). Similarly, in males, BW, body length, and head length were most closely correlated to age ($R^2 = 0.96$, 0.91, and 0.94, respectively).

Discussion

A large capital investment in the dairy industry is the cost associated with raising replacement female

Table 6. Quadratic models of growth traits as a function of age (in days) in Holstein calves

Item	Wt, kg	Body length, cm	Height, cm	Condition	Head length, cm	Radial length, cm	MC length, cm[a]	MT length, cm[a]	Tibial length, cm	Head width, cm	MC circ., cm[a]	MT circ., cm
Females												
Intercept	40.32	69.89	75.24	2.97	25.29	25.14	19.56	32.05	27.41	12.39	11.09	11.62
Intercept SE	2.96	1.56	1.17	0.11	0.40	0.42	0.53	0.51	0.62	0.23	0.22	0.27
Linear term, $\times 10^{-3}$[b]	233.03[z]	130.66[z]	126.57[z]	1.20	53.29[z]	21.37[z]	18.80[z]	42.54[z]	46.12[z]	12.70[z]	−17.97[z]	−14.24[z]
Linear SE, $\times 10^{-3}$	22.26	11.75	8.76	0.82	2.97	3.13	3.95	3.84	4.68	1.72	1.64	2.01
Quadratic term, $\times 10^{-5}$	536.8[z]	148.8[z]	48.6[z]	−0.4	20.8[z]	26.0[z]	9.8[x]	6.7	11.7[x]	14.1[z]	35.0[z]	41.1[z]
Quadratic SE, $\times 10^{-5}$	23.5	12.4	9.2	0.9	3.1	3.3	4.2	4.0	4.9	1.8	1.7	2.1
R^2	0.96	0.93	0.91	0.35	0.93	0.86	0.65	0.83	0.80	0.86	0.78	0.82
Males												
Intercept	43.21	71.36	77.50	2.96	25.83	25.63	19.94	32.78	27.84	12.83	11.86	12.32
Intercept SE	3.31	1.71	1.28	0.12	0.40	0.50	0.52	0.49	0.68	0.21	0.24	0.27
Linear term, $\times 10^{-3}$	328.86[z]	159.65[z]	104.37[z]	2.42[y]	48.06[z]	33.0[z]	14.64[z]	41.63[z]	52.91[z]	11.18[z]	−19.97[z]	−15.06[z]
Linear SE, $\times 10^{-3}$	24.9	12.87	9.65	0.86	3.02	3.76	3.93	3.71	5.12	1.61	1.77	2.04
Quadratic term, $\times 10^{-5}$	516.9[z]	121.9[z]	66.3[z]	−0.5	28.0[z]	15.3[z]	15.3[z]	8.8[a]	8.7[z]	14.6[z]	36.2[z]	40.7[z]
Quadratic SE, $\times 10^{-5}$	26.2	13.6	10.2	0.9	3.2	4.0	4.2	3.9	5.4	1.7	1.9	2.2
R^2	0.96	0.91	0.89	0.38	0.94	0.82	0.66	0.85	0.80	0.87	0.78	0.82

[a]MC stands for metacarpal, MT stands for metatarsal, circ. stands for circumference.
[b]Values within the table are to be multiplied by the designated factor.
[x]$P < 0.05$.
[y]$P < 0.01$.
[z]$P < 0.001$.

calves to first calving. Calving at less than 24 mo of age has economic advantage only if the females are healthy and of sufficient size at the time of first calving. The primary objective of the present study was to establish criteria for normal growth parameters and thereby provide producers a means to identify and retain those calves with optimal/adequate growth potential.

Although absolute weight gain is an important indicator, it must be accompanied by appropriate growth in skeletal and lean body mass. Given current controversies regarding age at first calving and subsequent lactation performance, there is a need to develop growth references representing contemporary standards of Holstein growth (Hoffman, 1997; Lee, 1997; Heinrichs, 1998). We have provided models of normal growth in female and male Holstein calves (Tables 6 and 7). For instance, normal contemporary female calf weight (kg) can be calculated by the following equation: $40.32 + 0.23303 \times age + 0.005368 \times (age)^2$. A given female calf's weight can be compared with that value to determine whether the calf is within the normal expected range of BW. The same approach can be taken for height (cm): $75.24 + 0.12657 \times age + 0.000486 \times (age)^2$. By establishing normal growth patterns, we can better identify superior and inferior growth in calves. Having these models, economic models for optimizing growth in females and males to further improve efficiency of growth, nutrient management, and monetary return on investments for production units can be developed.

Modeling early life-cycle growth patterns for cattle will help establish a point of reference, similar to anthropometry standards in human investigations. Such standards can aid future investigators to better understand aberrations in growth and assist producers in meeting objectives for replacement heifer development and for marketing males as beef. Recent large-scale prospective human studies have found increasing risks for death from diarrhea or pneumonia with increasing severity of malnutrition in children; risk for mortality increases incrementally for each standard deviation decline in weight or height, compared with reference population measures of growth (Fawzi et al., 1997; Manary et al., 1997; Yoon, 1997). Calf morbidity and mortality due to diarrhea and pneumonia is highest in the first 3 mo of life, and early calf morbidity has been associated with poor subsequent growth and lower milk production (Waltner-Toews et al., 1986; Curtis et al., 1989; Paré et al., 1993). Because studies similar to human investigations have not been done on cattle and such information would be useful, it is intended that the current clinical trial be the first of a series that will provide a diagnostic tool for producers, animal scientists, and veterinarians. Modeling early growth would be the preliminary step in devising criteria that will allow early identification of animals that have poor growth performance, potentially improve the quality of replacements, and meet current goals of calving at less than 24 mo of age.

In terms of parameters appropriate to evaluate the growing calves, both BW and head length were highly correlated with age. These growth parameters are easily obtained and discrete. Body length was also correlated with age but would be a more subjective measurement, and therefore selection on body length may prove more inconsistent/variable. The least reliable growth trait measured in this study was body condi-

Table 7. Quadratic models of growth traits as a function of age (in days) categorized for BLAD and twin status in Holstein calves

Item	BW, kg	Body length, cm	Height, cm	Condition	Head length, cm	Radial length, cm	MC length, cm[a]	MT length, cm[a]	Tibial length, cm	Head width, cm	MC circ., cm[a]	MT circ., cm
Females												
Intercept	32.39	67.39	73.61	3.12	25.15	24.68	18.21	31.70	26.29	11.86	10.37	11.13
Intercept SE[a]	2.96	1.56	1.17	0.11	0.40	0.42	0.53	0.51	0.62	0.23	0.22	0.27
Linear term, $\times 10^{-3}$[b]	233.03^z	130.66^z	126.57^z	1.20	53.29^z	21.37^z	18.80^z	42.54^z	46.12^z	12.70^z	-17.97^z	-14.24^z
Linear SE, $\times 10^{-3}$	22.26	11.75	8.76	0.82	2.97	3.13	3.95	3.84	4.68	1.72	1.64	2.01
Quadratic term, $\times 10^{-5}$	536.8^z	148.8^z	48.6^z	-0.4	20.8^z	26.0^z	9.8^x	6.7	11.7^x	14.1^z	35.0^z	41.1^z
Quadratic SE, $\times 10^{-5}$	23.5	12.4	9.2	0.9	3.1	3.3	4.2	4.0	4.9	1.8	1.7	2.1
Twin[c]	9.56^z	3.58^z	2.91^z	-0.21^x	0.44^z	0.80^z	1.42^z	0.64^z	1.51^z	0.69^z	0.80^z	0.64^z
Twin SE	3.81	2.01	1.50	0.14	0.51	0.54	0.68	0.66	0.80	0.30	0.28	0.34
BLAD[d]	-1.63	-1.08	-1.28	-0.04	-0.29	-0.35	-0.07	-0.29	-0.39	-0.16^{**}	-0.09	-0.15
BLAD SE	0.67	0.36	0.27	0.03	0.09	0.10	0.12	0.12	0.14	0.05	0.05	0.06
R^2	0.96	0.93	0.91	0.35	0.93	0.86	0.65	0.83	0.80	0.86	0.78	0.82
Males												
Intercept	34.90	70.64	72.58	2.59	25.42	24.44	19.53	31.29	26.93	12.20	11.65	11.77
Intercept SE	3.31	1.71	1.28	0.12	0.40	0.50	0.52	0.49	0.68	0.21	0.24	0.27
Linear term, $\times 10^{-3}$	328.86^z	159.65^z	104.37^z	2.42^y	48.06^z	33.0^z	14.64^z	41.63^z	52.91^z	11.18^z	-19.97^z	-15.06^z
Linear SE, $\times 10^{-3}$	24.9	12.87	9.65	0.86	3.02	3.76	3.93	3.71	5.12	1.61	1.77	2.04
Quadratic term $\times 10^{-5}$	516.9^z	121.9^z	66.3^z	-0.5	28.0^z	15.3^z	15.3^z	8.8^x	8.7^z	14.6^z	36.2^z	40.7^z
Quadratic SE $\times 10^{-5}$	26.2	13.6	10.2	0.9	3.2	4.0	4.2	3.9	5.4	1.7	1.9	2.2
Twin[c]	9.91^z	1.08^z	5.04^z	0.42^z	0.44^z	1.27^z	0.40^z	1.56^z	0.87^z	0.68^z	0.25^z	0.62^z
Twin SE	3.86	2.00	1.50	0.13	0.47	0.58	0.61	0.58	0.80	0.25	0.28	0.32
BLAD[d]	-1.61	-0.37	-0.11	-0.05	0.02	-0.08	$-0.01†$	-0.07	0.03	-0.04	-0.05	-0.07
BLAD SE	0.46	0.24	0.18	0.02	0.06	0.07	0.07	0.07	0.09	0.03	0.03	0.04
R^2	0.96	0.91	0.89	0.38	0.94	0.82	0.66	0.85	0.80	0.87	0.78	0.82

[a]MC stands for metacarpal, MT stands for metatarsal, circ. stands for circumference.
[b]Values within the table are to be multiplied by the designated factor.
[c]If born a twin, multiply value by 0; if born a single, multiply value by 1.
[d]If *CD18* genotype is homozygous normal, multiply value by 0; if *CD18* genotype is heterozygous for BLAD, multiply by 1.
[x]$P < 0.05$.
[y]$P < 0.01$.
[z]$P < 0.001$.

tion, followed by metacarpal length, indicating that these are highly subjective measurements not amenable to be used as selection criteria. In addition, body condition scores primarily assess body fat; calves at this young age are in a muscle accretion phase as opposed to fat accretion, resulting in small changes to body condition scores, again diminishing the utility of body condition scores. Finally, twin status, although clearly affecting BW, did not improve the fit of the regression equation when it was included in the model.

Previous studies have shown that increasing zinc supplementation yields increased feed efficiency and ADG for zinc-deficient calves (Miller and Miller, 1962; Engle et al., 1997) and improves health in immunologically compromised calves (Brummerstedt et al., 1971). However, contrary to the aforementioned calf studies and to human infant studies (Castillo-Duran et al., 1987; Michaelson et al, 1994), increased supplementation of zinc did not enhance growth measures of early development in the present trial regardless of the chemical form of zinc supplementation. The current study used calves that were not zinc-deficient, thereby demonstrating that supplementation of calves with zinc above the NRC (1989) recommended amount does not enhance growth performance.

The present study was the first to model the growth of BLAD carrier calves from birth to 90 d of age. In 1991, when widespread testing for BLAD carriers was begun, the carrier rate among over 2,000 bulls tested was 14.1% (Shuster et al., 1992). Among over 2,000 Holstein cows from across the United States in 1991, the carrier rate was 5.8%, and from over 2,000 Holstein heifers from the NAHMS dairy heifer study the carrier rate was 8% (Kehrli, 1993). Based on data in the present study from animals born in 1994, it appears that the carrier rate of BLAD among cows on commercial dairy farms may have increased to match the carrier rate observed among bulls used for artificial insemination. That being the case, we conjectured that the presence of a single mutant BLAD allele may affect growth of dairy calves.

Heterozygous BLAD calves neither have an advantage nor disadvantage in growth over normal calves. Although small differences in head width and metacarpal length for calves heterozygous for BLAD were detected, they were not readily explainable and were

considered neither detrimental nor beneficial for calf growth. Inclusion of BLAD status in the quadratic models of calf growth did not improve the model estimation. Practically, this is important because it suggests that there is no need to incur added expenses to remove calves heterozygous for BLAD under the assumption of poor growth performance. In fact, cows heterozygous for BLAD were determined to have an advantage by decreasing the estimated breeding value for two mastitis indicator scores: clinical mastitis and somatic cell count (Kelm et al., 1997). Caution must be exercised in interpreting the effect of BLAD status because other measures of calf performance, such as diarrhea, pneumonia, or death, were not evaluated in the current study. Further investigations are needed to develop health indices for homozygous normal calves compared with calves heterozygous for BLAD.

Implications

This study evaluated growth parameters of Holstein calves from birth until weaning at 90 d of age. Zinc supplementation above current governmental recommendations was shown not to be required as an accelerator of growth in Holstein calves from birth to 90 d. As expected, twins and heifer calves were smaller and grew more slowly than single calves. Heterozygous bovine leukocyte adhesion deficiency status was not considered to have a detrimental effect on calf growth. Further evaluation of normal growth patterns of Holstein calves, identification of environmental and genetic traits, and their effect on growth will allow for establishment of standards of performance to assess growth in production units.

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